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THE DERIVATION OF ORBITS, THEORY AND PRACTISE[1]

LESS than twenty-five years ago it was commonly accepted among astronomers and mathematicians alike that the orbit problem had been solved both in theory and in practise. Without detailing the well-known history of the development of orbit methods before that time it is sufficient to remind you that although Newton, after successfully integrating the differential equations in the problem of two bodies and verifying Kepler's laws, proposed a geometrical method which was successfully applied by Halley particularly in determining the orbit of the well-known comet which bears his name, the integrals derived by Newton were not translated into a thoroughly practical method for determining the constants or elements from the initial conditions furnished by observation until 1797 when Olbers published his famous method of determining parabolic orbits for comets from three observed positions. This special method was followed at the dawn of the last century by the general method of Gauss which permits of the determination of the elements from three observations without previous hypothesis regarding the eccentricity, a method applicable equally to comets and to planets. It is to be noted that both Olbers's and Gauss's methods rest on the previous analytical solution by Newton of the equations of motion in the two-

[1] Address of the vice-president and chairman of Section A, American Association for the Advancement of Science, read at a joint meeting of Section A, the American Mathematical Society and the American Astronomical Society, on Thursday, December 28, 1917, at New York.

body problem. In fact these orbit methods may be characterized as an evaluation of the numerical values of the constants or elements from given positions on the basis of the integrals found by Newton. It might be supposed that the mere evaluation of the numerical values of the constants of integration in a given case when the form of the integrals is known ought not to involve any considerable difficulties. But the solution of the unknown elements from the given equations of condition leads to very complicated expressions which can be solved only by successive approximations. This unfavorable condition arises from the occurrence of series in which the coefficients depend upon the unknown elements. Until the early nineties of the last century the chief aim of astronomers and mathematicians had been to modify the methods of Olbers and Gauss by transformations which would increase the degree of accuracy of the first and the convergence of later approximations. The most successful orbit methods would then be those which would yield the elements with the greatest degree of accuracy and with the minimum of numerical work.

The observations in general furnish three directions of three heliocentric positions of the body, each seen from one of three different positions of the observer. The problem of the older methods is to pass a plane through the center of the sun which cuts the three directions in such a manner that the body moves in accordance with the law of areas in the conic, which is defined by the three intersections of the plane with the directions, and by the center of the sun. It is evident at once that if the three directions are taken at short intervals they must be given with the utmost precision so that the parameters of the conic may be determined with any degree of accuracy.

In general a very large number of planes satisfying the required conditions may be drawn within the unavoidable errors of observation, so that every preliminary orbit is more or less indeterminate. Thus while a perfect theory might be available for the evaluation of the elements, in practise the numerical accuracy of the orbit will be limited. This limitation of accuracy in general increases with the ratio of the errors of observation to observed motion. In addition, even with perfect observations distributed over a sufficiently long heliocentric arc, cases occur in which the mathematical expressions for the solution of the elements lead to indeterminate forms. In some cases these indeterminate forms are inherent in the physical conditions of the problem. In other cases they may be avoided by proper mathematical devices or by a different mathematical treatment of the problem. One of the best known cases of indeterminateness arising from physical conditions is that in which the orbit plane coincides with the ecliptic. In this case the position of the orbit plane, usually defined by two elements, is given at once, but since each of the three observed directions furnishes but one independent condition, namely the longitude, while four elements remain to be found, the problem becomes indeterminate and requires a fourth observation for its solution. One of the best known cases of the other type of indeterminateness arising from the mathematical formulation of the orbit method is the so-called Ausnahmefall (exceptional case) of Oppolzer in Olbers's parabolic method. When the orbit is supposed to be parabolic only five elements need to be determined from the six conditions furnished by observation. The observed direction is usually given in right ascension and declination and may be considered as the intersection of two planes which may be introduced as given condi-

tions. Since the choice of these planes is arbitrary, as long as their intersection coincides with the line of sight Olbers reduces the number of available conditions by rejecting one of the arbitrary planes for the middle place or second observation and adopts for the other arbitrary plane that which corresponds to a great circle drawn through the observed place of the body and through the sun.

Since the three distances of the body are not furnished by observation they enter the problem as additional unknowns. Usually the distances are derived first, whereupon the solution of the elements becomes comparatively simple. In Olbers's method one of the fundamental relations for the determination of the distances at the first and third dates has the form $\rho_{III} = M\rho_I$, where M is equal to the product of the ratio of two triangular areas into the ratio of the trigonometrical sines of the perpendicular arcs drawn from the first and third observed places, respectively, to the great circle through the sun and the second observed place. The ratios of the triangles referred to form a very important consideration in many orbit methods. The triangles are contained between successive radii vectores from the sun to the body. For short arcs or intervals these triangles differ but little from the corresponding sectors bounded by the conic, and since according to the law of areas the sectors are proportional to the intervals, the triangles are very nearly proportional to the intervals. The ratios of the triangles may then be developed in series of which the first term is identical with the ratio of the intervals and of which the later terms contain the powers and products of the intervals, the inverse powers of the heliocentric distances r and their derivatives. They may be made to depend on the second heliocentric distance r and its derivatives. Since r and its derivatives depend on the elements in the orbit their values in general can not be known until the first approximation has been accomplished by placing the ratios of the triangles equal to the ratio of the intervals. The series representing the ratios of the triangles have been the subject of intensive study in connection with the orbit methods resting on the integrals of Newton. The most exhaustive study of the true radii of convergence of series of this type is due to Moulton. He demonstrates analytically the empirical conclusions of astronomers that the series may lose their applicability for comets observed near perihelion at a moderate distance from the sun, while for minor planets in general they give universal satisfaction.

In referring to the indeterminateness in Olbers's method I am not at this moment concerned with any inaccuracies that may arise from his using in the first approximation the ratios of the intervals for the ratios of triangles. The indeterminateness I am referring to arises from the fact that when the first and third observed positions lie on the auxiliary great circle through the second place and the sun, referred to above as being introduced by Olbers, then both the perpendiculars from the first and third places on this great circle become zero and M becomes indeterminate. It becomes nearly indeterminate when the three observations lie approximately in the great circle through the sun, and the degree of indeterminateness in such cases depends upon the magnitude of the errors of observation as compared with the magnitude of the perpendiculars. It is evident that perpendiculars of but a few seconds accurately derived from precise observations would still yield a working first approximation, while larger perpendiculars comparable to the errors of observation would lead to fallacies or yield nothing. Here

we have a significant contrast of the interpretations with reference to accuracy obtainable from theory and practise. Theoretically small perpendiculars in Olbers's method would lead to indeterminateness, but in practise it is not the absolute magnitude of the small perpendiculars that counts so much as their uncertainty due to errors of observation. To return once more to Olbers's method, when his mathematical formulation leads to a practical indeterminateness the difficulty may be removed at once by substituting for Olbers's great circle through the second place and the sun a great circle perpendicular to it. This choice of great circle evidently produces a maximum value of the perpendiculars drawn to it from the first and third places, so that the effect of the errors of observation is minimized.

It must not be supposed that the conditions of indeterminateness just referred to were not known to theoretical astronomers until recent times. In his classic "Lehrbuch zur Bahnbestimmung," the second edition of which was published in 1882, Oppolzer sets forth clearly and concisely the significance of errors of observation with reference to small quantities which are theoretically of a high order of smallness, when the intervals or motion are considered quantities of the first order. My own aim and that of those associated with me at the University of California has been to treat each case on its own merits from the numerical point of view and to ascertain at the outset the uncertainty which must necessarily remain in the result. As this uncertainty corresponds to a region of possible numerical results clustering around the physical solution or in case of multiple mathematical solutions around these, all of which correspond to orbits that will satisfy the observations within their errors, I introduced the term *range of practical solutions* in a paper read at the International Congress of Arts and Sciences at St. Louis in September, 1904, and have at the same time and again later set forth the numerical conditions producing a range of practical solutions. In the modifications of the formulæ, for computing orbits so as to secure the greatest accuracy with the least expenditure of numerical work this principle has been constantly borne in mind. I emphasize this point because this distinction between practise and theory has not been well understood. Moulton, in a very exhaustive memoir on the "Theory of Determining Orbits," published in the *Astronomical Journal* in 1914, to which further reference will be made later, also seems to have failed to recognize the significance of our work in this regard, although it was set forth in detail in another form in Buchholz's "Klinkerfues Theoretische Astronomie," third edition, 1912, which Moulton has reviewed. In the first example published in this work I was careful to place a dot over the last digit of every fundamental quantity that could be relied upon.

To facilitate our further discussion it may be well to trace in outline the fundamental principles of the methods of Olbers and Gauss as set forth by Oppolzer in a masterly manner. Olbers's and Oppolzer's parabolic methods yield a solution of the first and third geocentric distances from the equation $\rho_{III} = M\rho_I + m$ and the well-known Euler's equation expressing the intervals between the first and third dates in terms of the sums of the radii vectores drawn from the sun to the first and third places and the chord joining these two places. With Olbers's choice of the great circle through the middle place m becomes zero. In both methods the ratios of the triangles are replaced in the first approximation by the ratios of the intervals. Even

then the solution is accomplished only by successive approximations or trials in the course of which, however, higher terms of the series in the ratios of the triangles may be taken into account. It is customary to assume as a first approximation that the sum of the first and third radii vectores is equal to 2 astronomical units. Convergence of the approximations has been facilitated by Oppolzer by differential relations which give the correction to be applied to the initial value of $r_{\mathrm{I}} + r_{\mathrm{III}}$ so that it may agree with the value derived at the end of the trial. In the course of ordinary trials without the use of differential relations the final values of the distances of one trial form the initial values in the next trial. In the method of differential corrections such corrections to the initial value of one trial are derived differentially from the differences between the initial and final values in the same trial as will produce an agreement of the initial and final values in the next trial. The number of approximations required by the ordinary trials is in general far in excess of that required by the method of differential correction.

Gauss's method as formulated by Oppolzer may be started from the equation $Ax + By + Cz = 0$, which expresses that the body moves in a plane through the sun, x, y, z being the heliocentric rectangular coordinates referred to the sun. When this equation is written out for each of the three places and when the eliminant of the three equations is written down in the form of a determinant this determinant may be developed either in terms of co-factors of the x, or the y, or the z. For instance, in co-factors of x we have

$$x_{\mathrm{I}}(y_{\mathrm{II}}z_{\mathrm{III}} - y_{\mathrm{III}}z_{\mathrm{II}}) - x_{\mathrm{II}}(y_{\mathrm{I}}z_{\mathrm{III}} - y_{\mathrm{III}}z_{\mathrm{I}}) + x_{\mathrm{III}}(y_{\mathrm{I}}z_{\mathrm{II}} - y_{\mathrm{II}}z_{\mathrm{I}}) = 0.$$

The coefficients of x here represent the projections of double the triangular areas $[r_i\ r_j]$ upon the yz plane. By dividing out by one of these areas the two resulting coefficients represent the ratios of the projected triangles and since the triangles are projected on the same plane these ratios are the same as the ratios of the triangles themselves. As stated before, instead of developing the determinant by co-factors of x it may also be developed by co-factors of y and z. We thereby obtain the same equation written in two additional forms. Every equation is identically equal to zero, if the terms are multiplied out. But if we can assume the numerical values of the ratios of the triangles to be known from other sources and if we express in each of the three equations the heliocentric rectangular coordinates in terms of the geocentric polar coordinates and of the solar coordinates so that, for instance,

$$\frac{[r_{\mathrm{II}}r_{\mathrm{III}}]}{[r_{\mathrm{I}}r_{\mathrm{III}}]}(\rho_{\mathrm{I}}\cos\alpha_{\mathrm{I}}\cos\delta_{\mathrm{I}} - X_{\mathrm{I}}) - (\rho_{\mathrm{II}}\cos\alpha_{\mathrm{II}}\cos\delta_{\mathrm{II}} - X_{\mathrm{II}}) + \frac{[r_{\mathrm{I}}r_{\mathrm{II}}]}{[r_{\mathrm{I}}r_{\mathrm{III}}]}(\rho_{\mathrm{III}}\cos\alpha_{\mathrm{III}}\cos\delta_{\mathrm{III}} - X_{\mathrm{III}}),$$

then we arrive at three equations with the geocentric distances as unknown quantities. Now if the ratios of the triangles could be known at the outset, it is evident that the geocentric distances can be obtained by the solution of these three equations. The first approximation, depending upon the degree of accuracy with which the ratios of the triangles are introduced, is generally referred to as the first hypothesis and the accuracy of the geocentric distances and therefore of the whole solution which depends upon them is referred to as being of the zero, first, or higher order with reference to the intervals or motions. The choice of equal intervals always increases the accuracy by one order. Simple as this process seems in theory, it becomes very complicated in practise, because in general a first approximation can not be obtained by merely using the ratios of the intervals as numerical expressions for the ratios of

the triangles. It is necessary to introduce at the outset one or more of the terms involving the inverse powers of the heliocentric distance r and its derivatives, and these can not be known until the geocentric distances have been obtained, r being derived from the triangle which has at its vertices the observer, the sun, and the body. The angle at the observer is known by observation, the distance of the sun from the earth is known, and ρ being assumed, r may be found. But since neither r nor ρ is known at the outset, the solution must be accomplished by trial and error. Here, as before, the method of differentially correcting the first approximation on the basis of the difference between initial and final values in a trial is very effective. Thus the first hypothesis involves a series of trials for the solution of r and ρ, and it is accurate to zero, first, or second order, and so forth, according to the number of terms in the ratios of the triangles introduced in the first set of trials for the distances, which trials become, of course, the more complicated, the more terms are introduced. A practical limit is thus set at once. The second hypothesis depends upon the computation of the remaining terms of the series in the ratios of the triangles on the basis of values derived from the first hypothesis. While these values may be sufficient for the higher terms the lower terms taken into account in the first hypothesis still remain inaccurate since they do not contain the final numerical values of the unknowns. This is important because it involves successive resubstitution of the improved values in all terms of the series. We shall see later that these complicated manipulations have recently been removed by Charlier by completing a purely analytical solution proposed by Lagrange. In passing from one hypothesis to the next it is necessary, as previously stated, to calculate the remaining terms of the series representing the ratios of triangles. Oppolzer ingeniously computes the whole remainder in a closed form, but in determining the numerical value of the closed remainder must perform successive approximations, as I say, merely to get the remainder. These approximations involve the complicated expression of the ratio of a sector of a conic to the corresponding triangle. Thus we see that in Oppolzer's formulation, which is the most accurate yet proposed, it is necessary first: to undertake several hypotheses; secondly: within each hypothesis to perform a number of trials for the distances; and, thirdly: in passing from one hypothesis to the next to perform approximations involving the ratio of sector to triangle. The application of the method of differential correction, so successfully applied in the trials for the distances, in place of these several cycles will take up in one operation all of these cycles of approximation as will be referred to later.

It is not necessary to go into the various and numerous devices which have been proposed during the past century to facilitate the various cycles of approximation referred to. Be it sufficient to say that the highest degree of accuracy has been obtained in this country by Gibbs in his vector method, which in the first hypothesis takes account of terms of the fourth order in the ratios of the triangles. But although this method is the most accurate of all the so-called methods in the first hypothesis it unfortunately requires too large an amount of numerical work in the first approximation and does not readily lend itself for application to a second hypothesis. It has, therefore, failed to come into universal use.

I have already referred to the methods hitherto described as "the older methods." They have been set down in various excellent formulations, particularly by Klinker-

fues, by Watson in this country, by Oppolzer, by Buchholz, by Tisserand, and others, and are in use to the present day in accordance with the various formulations, but unfortunately without being duly appreciated in all cases by computers with reference to their numerical significance, that is, with reference to the validity of the results which they produce as conditioned by partial indeterminateness or range of practical solutions. Furthermore, to cite from my paper on "Preliminary Statistics on the Eccentricities of Comet Orbits":

> Ever since the first computation of a comet orbit was made, it has been customary to derive a parabola as a first approximation, and to attempt a more general solution only if the deviations of the observed positions from the most probable parabola were in excess of the probable errors of observation. This custom has become so thoroughly fixed in astronomy that even now it would be considered absolutely unwarranted to suspect a comet of moving in an ellipse if by a little stretching of the probable limits of observational error a parabola could be found to represent the observed positions. A prejudice has always existed and exists now in favor of the parabola for comets. This prejudice is largely due to the many published parabolic comet orbits. A further reason lies in the fact that the first geometrical and analytical methods for solving a comet orbit were parabolic. The solution of an elliptic orbit was originally possible only in cases like Halley's comet, in which more than one appearance had been observed so that one of the unknowns, the period, became known.

The procedures in the older methods for the derivation of a parabolic and the derivation of a general solution are so different that when it is recognized that a parabolic orbit or conditioned solution is not possible, a fact which does not reveal itself until after many fruitless attempts at a parabolic solution have been made, it is necessary to discard most of the previous numerical work and to start anew with the formulæ for a general solution. An illustration of the labor involved in this antiquated process is furnished by the published work of one of the leading European astronomers on the preliminary orbit of comet 1892 II. (Holmes). Three observations at equal intervals of four days were available in this case. The computer attempted a parabola and, finding that he could do nothing with the ratios of the triangles in improving his orbit, finally resorted to an arbitrary variation of M referred to in Olbers's method as the ratio of the third to the first geocentric distance, thus producing four different parabolic orbits with ephemerides from which to choose, none of which admittedly represented the given observations. Only later and still greater discrepancies between observation and the predicted path lead the computer to resume the computation without hypothesis regarding the eccentricity. In due course of time this general solution yielded a short period ellipse. Here is a bit of practise still in use among many computers which, if applied in the business world, would involve an enormous cost of operation. Mr. Shane, one of my students, applied my formulation of the Laplacean method to this case and obtained the true ellipse in the first approximation or by a direct solution without difficulty in a few hours.

Nor is it always safe to assume the nature of the object and the character of its orbit from its appearance. Thus some comets are of a star-like appearance when discovered and can not be distinguished from asteroids, and to prejudice the character of the orbit at the outset may lead to unnecessary complications. It is not improbable that some of the short periodic orbits published for supposed minor planets which have become lost are really very eccentric orbits of comets which would account for their failing to be reobserved in their predicted places. Just how many of the published orbits of the hundreds of planets and comets are entirely reliable is

difficult to say until a thorough examination shall have been made of the range of practical solution for each case. When a planet or comet has been observed for a considerable length of time, or on several returns, the elements require no further examination if they have been properly corrected on the basis of the observational material. But the comet and planet lists are full of orbits based upon comparatively short arcs and the lists contain little indication of the degree of accuracy in each case.

Sometimes when physical and mathematical indeterminateness does not prevail the range of solution with precise observations is quite limited even for a very short arc, and the resulting orbit is fairly accurate. In other cases conditions may be such that even for a comparatively long arc the orbit is inadequate to secure rediscovery at a later return. Comet *e* 1913 Neujmin was of a star-like appearance and admitted of a high degree of accuracy in the observed positions. The first three observations at one-day intervals admitted of the determination of a periodic orbit agreeing closely with a more accurate orbit determined from a 38-day arc. On the other hand, orbits of planet (702) discovered in 1910 based on arcs of several months show a wide range of practical solution amounting to about four degrees in the eccentricity.

An accurate knowledge of the eccentricities of comet orbits is of importance in determining the origin of comets. On theoretical grounds it has long been recognized that parabolic orbits are practically impossible if comets came from without the solar system, formerly a favorite theory of astronomers. The majority of orbits should be elliptic if comets have their origin within the solar system. A rare parabola and some hyperbolas might, of course, be accounted for through the perturbations of the major planets on an original ellipse. But if comets came from without they should be predominatingly hyperbolic. Now the published comet lists show that about three fourths of all comet orbits have been found to be parabolic. A study of the published eccentricities of comet orbits on the basis of the accuracy with which, and the length of time during which they were observed has shown conclusively that all comet orbits are elliptic if observed with sufficient accuracy and for a sufficient length of time. This conclusion was received with doubt when I first announced it in 1907 on the basis of a study of the eccentricities of comet orbits. That three fourths of the comet orbits are parabolic is due to the fact that comet orbits in general have a high eccentricity and that the parabola lies within the range of possible solutions. Since the lower limit of the eccentricity has never been sought the orbits have simply been set down as parabolic and much confusion has been created with reference to the determination of the origin of comets. A few well-determined hyperbolas do exist, but Stroemgren has shown that these are accounted for by perturbations of the original ellipses on the part of the major planets. The high eccentricity found for comet orbits lies in the nature of things. Long-period comets can not come within the range of visibility from the earth unless their orbits are highly eccentric. The others must remain invisible. It is only within recent years that the old idea that comets are visitors from without the solar system has been abandoned. Reference to the existing confusion in regard to the origin of comets is made here only because it is clear that if in the past astronomers had worked by methods which readily enable the computer to ascertain the range of possible solutions, particularly the lower limit, three fourths of all

comet orbits would not have been set down as being parabolic and much analytical work with reference to the origin of comets would have been avoided. Yet there is a practical advantage in adopting a preliminary parabolic solution for a comet when the range of solutions is very large and when this range includes the parabola. For since the majority of comet orbits have high eccentricities the adoption of a preliminary short-period orbit would later involve a more radical correction than the adoption of a preliminary parabola. Of course within the physical indeterminateness or the practical range of solutions any and all of the orbits satisfying the observations within their errors are equally justified, but even to this day it is a reflection on the astronomer if the period or eccentricity of his preliminary orbit must be increased to satisfy later observations, while it is quite the proper thing to publish a parabola and later to find the orbit short period even if such short period and eccentricity could have been derived at the outset. Thus in the case of comet Neujmin referred to above parabolic orbits were still insisted upon, while the comet closely followed our short-period orbit from a two-day arc. It has been my frequent experience that elliptic orbits with a fair degree of accuracy could be determined from the first three observations, while other computers continued to produce parabolas which could be shown not to lie within the range of solution and resulted from the use of approximate methods.

In anticipation of stating the many advantages introduced by the modernization of the method originally proposed by Laplace I have already dwelt on three important considerations, namely, first, on the complications involved in the successive hypotheses and approximations of the older methods; secondly, on the waste of time in applying different formulas for a conditioned and a general solution so that with the abandonment of a parabola it is necessary to make a new start; and thirdly, on the significance of the range of solution as derived from partial indeterminateness depending upon the shortness of the arc and upon the effect of error of observation on small significant coefficients. My own attention was directed to Laplace's method by a memoir of Harzer. Laplace's method appeared in 1780 in a memoir and later in his Mécanique Céleste. Prior to him, in 1771 Lambert had produced his famous theorem based on geometrical considerations. Later, in 1778 Lagrange showed that Lambert's equation leads to an equation of the seventh degree, the fundamental equation of the orbit problem which also occurs in the older methods and which Charlier proposes to designate as Lagrange's equation. Laplace and Lagrange mutually inspired each other to further important developments of the orbit problem. Laplace starts with the three differential equations of motion of the second order for the two-body problem under the Newtonian law of attraction as applied to the motion of a material point (the object) about the sun. He then expresses the heliocentric rectangular coordinates of the object in terms of its geocentric coordinates and the heliocentric coordinates of the earth. The rectangular coordinates are then replaced in terms of polar coordinates, and thereby three equations are derived which give the geocentric distance ρ, its velocity ρ', and its acceleration ρ'' at the epoch in terms of the observed coordinates (for which we may choose α and δ, their velocities (α' δ'), and their acceleration (α'', δ''), and also in terms of the unknown heliocentric distance r of the object and known quantities, depending upon the motion of the earth about the sun.

If, therefore, for the present, we assume the coordinates α, δ, their velocities α', δ', and their accelerations α'', δ'' to be known, we have three fundamental equations for the solution of the four unknowns ρ, ρ', ρ'', and r. The fourth equation is derived from the triangle sun-earth-object, and involves ρ, r, and known quantities. By elimination the problem reduces to Lagrange's equation of the seventh degree with not more than two positive real roots, which may be interpolated to six decimals from a table which I have prepared for this purpose, so that the solution may be accomplished without the hitherto necessary laborious numerical approximations.

The direct solution which has just been outlined corresponds to the so-called first hypothesis of other methods. It is evident that the accuracy of Laplace's direct solution depends upon the accuracy of the fundamental observational data for which we have chosen α, δ, α', δ', α'', δ''. If the epoch is chosen to coincide with the date of one of the observations, then α, δ are fixed numbers, and the accuracy of the Laplacean solution depends upon the accuracy of the adopted values of their velocities and accelerations or, which is an equivalent statement, upon the accuracy of their first and second differential coefficients. In practically all other methods the accuracy of the solution depends upon the accuracy of the adopted values of the ratios of the triangles. Unfortunately the method of Laplace has been prejudiced by Lagrange until recent times through a letter addressed to Laplace, in which he says that while analytically Laplace's method constitutes the simplest solution of the problem, in practise it does not afford corresponding advantages because the differential coefficients could not be determined with the necessary accuracy. This far-reaching statement Lagrange intended as a mere opinion which he proposed to verify later by mathematical demonstration. It is a remarkable fact that Lagrange's opinion, although never verified by himself, has been the chief cause of retarding the further development of the Laplacean method until recent times.

Nevertheless, several attempts at giving it a practical formulation have been made during the last century, but with indifferent success. With reference to the disrepute which Laplace's method and all formulations based upon the same have been held until recent times and for a statement of its actual merits I may refer you to my address delivered before the International Congress of Mathematicians in August, 1912. Laplace's method leads to the usual equation of the seventh degree, which, as stated above, we shall refer to as Lagrange's equation. The roots of this equation have been frequently studied by Cauchy, Mrs. Young (Grace Chisholm), Oppolzer, and others. In recent times a classic study of the equation has been published by Charlier, who not only clarifies the existing conditions which will lead to a multiple solution, but exhibits these conditions geometrically by dividing space into four regions symmetrical with reference to the line joining the earth and sun as central axis, and showing that two solutions exist when the body is in two of these regions, and one solution when the body is in the other two. In certain cases it is not possible to distinguish the mathematical from the physical solutions, so that either a fourth observation must be employed in the original solution or the mathematical solution must be eliminated on the basis of difference between theory and later observation.

My own formulations of Laplace's method need be referred to but briefly. The results are chiefly that the whole process has

been extremely simplified. A conditioned solution may be made on practically the same plan as a general solution. Criteria have been introduced to distinguish between the feasibility of solution with or without assumption regarding the eccentricity. Provision has been made for passing from one class of orbit to another in the course of the computation without repeating the solution. Numerical criteria have been set up to distinguish the physical from the mathematical solutions in the case of three roots which may occur in the parabolic method. A method has been provided for completely eliminating the parallax, as has been done in the case of Planet *MT* by Dr. E. S. Haynes, since in this case the possibility of a solution rested on such elimination. The various approximations for the solution of distances is avoided. In a general solution the distances are taken from a table. The accuracy attainable in each case can be ascertained in advance and the range of solution definitely determined. Series corresponding to the ratios of the triangles, which do not enter, however, in the original solution but only later after the distances have been determined, have been replaced by closed expressions which avoid slow convergence or divergence in case of comet orbits observed near perihelion and at a moderate distance from the sun. The whole cycle of hypotheses and approximations of the older methods and all initial inaccuracies are taken up by a method of differential correction. In the case of highly disturbed satellites, such as the ninth satellite of Jupiter, the orbit solution has been made possible by extending the formula so as to take account of the perturbations in the first approximation. Closed expressions in the differential correction of an orbit now make it possible to apply the method to any and all conditions, particularly to arcs of any length.

It is not possible to dwell further on these advantages, yet reference may be made to some important results which make unnecessary extensive investigations hitherto in use. In the case of comet 1910*a*, which was discovered near perihelion and at a moderate distance from the sun, a variety of preliminary orbits were derived by various computers. Through the work of Oppolzer, Charlier, and myself, it was already known that cases of three mathematical solutions might be possible. Tscherny classified all the different preliminary orbits that had been derived for this comet and showed that clearly they represented three groups, each group representing a range of solution clustering about a mathematical solution. Each computer had produced a perfectly legitimate orbit within the errors of observation, none recognizing that his orbit was one belonging to one of the three ranges, or that multiple solutions existed. In my short methods simple criteria are given for determining the existence of three mathematical solutions of the equation of the sixth degree for a parabola. As soon as observations became available the method was applied by Miss Levy and three distinct values of the geocentric distance at the middle date and the range of each were obtained. A simple consideration leads to the elimination of the two fictitious parabolic solutions, as there can be at most two general solutions, also either one or three parabolic solutions, and as only one parabolic solution can agree with a general solution. By this process the physical solution was at once determined. The two general solutions corresponding to the problem are readily taken from the table so that all five roots, two general and three parabolic, are available simultaneously and with little effort. Therefore, there really exists no reason why hereafter a computer should ever be

misled to derive a parabola corresponding to a solution other than the physical solution. By the method of the greatest common divisor Picard has reduced the equations for general and parabolic orbits to a linear equation giving the only possible parabolic solution.

The other point on which I desire to dwell is that of the identification of newly discovered planets or comets with objects previously observed and for which orbits are available. More than once it has been found in the case of a newly discovered comet that the inclination, node, and perihelion distance of the parabolic solution resemble within the range of the solution the corresponding elements of some former parabolic comet. By introducing a period corresponding to one or more revolutions between the dates of the perihelia of the two comets the original solution may be turned into a conditioned solution based on a definite period. In no case where definite reasons for such procedure existed did this experiment fail of proving the identity of two comets. Thereby the two objects instead of being different comets with parabolic orbits were recognized to represent a single comet, moving in a definite ellipse. It is quite probable that a proper study of the existing comet lists may readily lead to many identifications. Many pretty results might be cited in connection with the various advantages to which I have referred above as obtainable from a proper formulation of Laplace's method. Undoubtedly there are cases where Gauss's and Olbers's methods would converge more rapidly than my own formulation of Laplace's method, but these are readily ascertained at the outset. Orbits have been computed at Berkeley for practically every comet since the methods have been perfected, and so far every case has readily yielded to a solution.

In recent times notable memoirs have been written on orbit theory by Harzer, Charlier, and Moulton. I have not as yet had an opportunity to study Harzer's new geometrical methods with respect to their practical value. With the claims made in Moulton's memoir on the "Theory of Determining Orbits," published in the *Astronomical Journal* in 1914, I can not, unfortunately, find myself entirely in accord. The object of the memoir is set forth to be, on the one hand, to clarify the problem mathematically, and, on the other, to define the extent of the indeterminateness. In spite of the noted mathematical skill of Moulton it appears that although his forms have the merit of symmetry, his treatment of the problem which involves determinants of the ninth order, though readily reduced, offers no advantages over the simplifications arising from earlier combinations of geometrical and dynamical relations. To his misconception of the practise of the computers at Berkeley, with reference to the interpretation of the accuracy of their results, I have already referred. These misconceptions apply also to the significance of a number of theoretical and practical points, particularly to his interpretation of the vanishing of the chief determinant. Quite contrary to his statement in his "Celestial Mechanics" that in general the expressions for ρ and ρ' become indeterminate when the determinant referred to is zero and that they are poorly determined when it is small, it may be shown that the orbit is in general well determined when the determinant is definitely zero or definitely small, and that the determinateness of the solution does not depend so much on the numerical value of the determinant, but upon the accuracy with which this numerical value can be found. Thus a large range of solution may result for a comparatively large value of the determinant, if

that value has a large percentage error. These conditions have been partially set forth in Buchholz's "Klinkerfues Theoretische Astronomie," but reference has been made by Moulton only to the first and initial draft of the methods as published in 1902. It is, of course, not my intention at this time to undertake a detailed analysis of Moulton's memoir. This must be deferred to some more appropriate time and must be done in more explicit form. With reference to the formulation finally adopted by Moulton it may readily be shown that it reverts to Gauss's method.

The most notable and classic contributions to the orbit theory in recent years have been made by Charlier. In a number of memoirs he has set forth the fundamental principles of the problem and has thrown much light on the subject with reference to many details, but his most important contribution is the resumption of Lagrange's incomplete analytical solution, a pure analytical solution in series, which admits of determination of the higher terms by direct computation without involving successive approximations of any kind nor requiring an improvement of the lower terms. His theoretical developments hold out the highest promise of successfully conquering the problem in practise without the complications existing in the older methods. But at present serious practical difficulties still exist, chief among which is that the series involved become extremely complicated when a high degree of accuracy is required, and that the method is subject to several of the limitations of the older methods. If these complications and limitations can be removed the method will be the best in existence. One of the chief limitations affecting practise consists in the fact that it is a general method and that it therefore may lead to orbits within the range of solution which are not acceptable from experience. It has been applied to the computation of several planet and comet orbits by Charlier and his associates. In the case of Comet *e* 1906 the resulting orbit is an hyperbola with an eccentricity 1.46. This seems to represent a solution near the upper edge of the range. A parabolic solution has been produced from the observations without difficulty in the first approximation by my formulation of Laplace's method by Miss Levy. In the case of another comet the elements are slightly hyperbolic; in the case of planet (702) the orbit deduced by the Charlier-Legrange method from an arc of two months gives an angle of eccentricity differing by nearly four degrees from the corresponding angle deduced near the upper possible limit by Miss Levy. Under these circumstances it would be difficult to decide where to stop in the computation of the terms of his series in relation to the possible range of solution.

From the somewhat disconnected and incomplete observations which I have just made on the methods of determining orbits it is seen that the interest of investigators is directed along two distinct lines, purely mathematical and practical. A proper adjustment between the two is required by the demands of astronomical science. In this connection and in conclusion I may make reference to the possibility of determining the orbit of a highly disturbed satellite from a limited number of observations on the basis of Laplacean principles. It is not necessary to await the evaluation of all the 18 integrals of the problem of three bodies for the purpose of setting up a satisfactory orbit method. Laplace's method for the two-body case is not based on Newton's integrals, but by introducing numerical values for the geocentric velocities and accelerations in α and δ the differential equations are

transformed into algebraic equations admitting of easy solution of r, ρ, its velocity and acceleration. This equation has been found to be of the seventh degree or of the eighth if the always existing root ρ equal zero be included. My equation for three bodies, that is, for the solution of orbits of disturbed bodies, is of the twenty-eighth degree and admits at most of three solutions, the examination of which makes it possible to decide whether a body is a satellite, planet, or comet, in cases where the physical appearance of the object does not settle this question in advance.

In spite of the extensive investigations that have been made on the orbit problem there is room for much improvement both in theory and in practise, improvement which can not fail to come through proper cooperation of astronomers and mathematicians.

A. O. Leuschner
University of California

SCIENTIFIC EVENTS

THIRD INTERSTATE CEREAL CONFERENCE

An executive committee, representing the U. S. Department of Agriculture and state experiment stations, has called a third interstate cereal conference to be held at Kansas City, Coates Hotel, June 12–14. This conference, which has the approval of the Secretary of Agriculture and the directors of the state stations, is for the purpose of discussing questions involved in and work essential to accomplish the enlargement of cereal production and the economic utilization of cereals during the existing war emergency. In addition to the representatives of the institutions mentioned, the flour mills, grain inspection departments, grain dealers and manufacturers of cereal foods and corn products of the grain states are invited to send delegates. Some of the subjects to be discussed are:

Agricultural War Measures in Kansas.
Waste in Cereal Production on the Farm.
The Importance of Good Seed.
The Proportion of Flour and By-products in Milling.
The Preparation of Land for Wheat.
The Use of Barley as a Food.
Corn as a War Crop.
Treatment of Seed Grain for the Prevention of Smuts.
Analysis of the World's Wheat Supply.
The Importance of Grain Sorghums.
Federal Standards for the Grading of Wheat.
Weed Seeds in Relation to Grain Grading.
The Importance of Testing Spring Wheat for Germination.
The Next Step in Improvement in Wheat Cropping.
The Work of Committee on Seed Stocks, U. S. Department of Agriculture.

The delegates to the conference are invited to Manhattan, Kansas, on June 15, to inspect the cereal field work of the Kansas Agricultural Experiment Station.

Charles E. Chambliss,
Secretary
U. S. Department of Agriculture,
Washington, D. C.

THE SOCIETY OF INDUSTRIAL ENGINEERS

The Society of Industrial Engineers, a national organization, the membership of which is to comprise men and women who are industrial engineers, professional technical engineers, accountants, managing executives of commercial and industrial activity, writers, educators and students, was planned in Chicago on May 26. The Society will be permanently organized in Washington, on June 15, on which date the directors have been called to meet.

Charles Buxton Going, for twenty years editor of the *Engineering Magazine,* New York, was chosen provisional President and *pro tem* chairman of the board of directors which was chosen at the session. This board, comprising 15 prominent men from various sections of the United States, the majority of whom have accepted, includes:

Charles Buxton Going, New York; C. E. Knoeppel, industrial engineer and organization counsel, New York; Frank B. Gilbreth, industrial engineer, Providence, R. I.; E. C. Shaw, vice-president The B. F. Goodrich Co., Akron, Ohio; Harrington Emerson, industrial engineer, New York; Charles Piez, president

The Link Belt Co., Chicago; Irving A. Berndt, manager betterment department, Joseph T. Ryerson & Son, Chicago; G. DeA. Babcock, production manager The H. H. Franklin Manufacturing Co., Syracuse, N. Y.; Willard E. Hotchkiss, dean Northwestern University School of Commerce, Chicago; Harry Franklin Porter, Detroit Executives' Club, Detroit, Mich.; H. Thorpe Kessler, President Western Efficiency Society, Chicago; Dexter Kimball, Cornell University, Ithaca, N. Y.; Morris L. Cooke, industrial engineer, Philadelphia; C. Day, industrial engineer, Philadelphia; Herman Schneider, school of engineering, University of Cincinnati, Ohio.

Temporary committees are now at work. Upon completion of the organization its services will at once be tendered to the government, through Howard E. Coffin, chairman of the advisory committee, Council of National Defense, and such other committees as can utilize the services of The Society of Industrial Engineers.

The temporary executive committee consists of Irving A. Berndt, chairman; F. M. Simons, Jr.; H. Thorpe Kessler; H. A. Rose, G. C. Dent, Harry Franklin Porter, C. A. Knoeppel, Willard E. Hotchkiss, S. T. A. Loftis and Charles Buxton Going. G. C. Dent is temporary secretary and H. Thorpe Kessler, treasurer.

The plan of organization adopted provides for a service or promotion bureau under the direction of a vice-president, and divided into two sections: (1) Advisory, and (2) Performing.

This is separate and distinct from the organization of the society proper, although under the direction of the president. The function of this bureau is to list as soon as possible all the industrial specialists in the country who may be qualified to serve either as advisers or as actual directors of efficiency work. From these two groups of advisers and performers the society will draw those necessary to carry on whatever work may be delegated to it in connection with perfecting preparation for war.

All men who possess qualifications that would enable them to serve in either or both of these sections are urged to get in touch with the acting secretary of the organization, G. C. Dent, 327 South La Salle Street, Chicago, as soon as possible.

I. A. BERNDT,
Chairman, Executive Committee.

SUBCOMMITTEES OF THE COUNCIL OF NATIONAL DEFENSE

As has already been noted in SCIENCE seven committees of the Council of National Defense have been organized. Their committees and their chairmen are:

Transportation, including railroad and motor transportation and communication, Daniel Willard, chairman.

Munitions, manufacturing, including standardization and industrial relations, Howard E. Coffin, chairman.

Raw Materials, minerals and metals, Bernard M. Baruch, chairman.

Labor, including conservation of health and welfare of workers, Samuel Gompers, chairman.

Supplies, clothing, etc., Julius Rosenwald, chairman.

Science and Research, including engineering and education, Hollis Godfrey, chairman; Henry E. Crampton, vice-chairman.

Medicine, including general sanitation, Franklin H. Martin, chairman.

Under *Raw Materials,* subcommittees have been formed with chairmen as follows:

General chemicals, William H. Nichols; *fertilizer,* Horace Bowker; *alkalis,* J. D. Pennock; *acids,* E. H. Grasselli; *miscellaneous chemicals,* Edward Mallinckrodt, Jr.; *cement,* John E. Morrow; *alcohol,* Horatio S. Reubens; *aluminium,* Arthur V. Davis; *asbestos,* Thomas F. Manville; *brass,* Charles F. Brooker; *coal tar products,* Wm. H. Childs; *lumber,* R. H. Downman; *lead,* Clinton H. Crane; *mica,* L. W. Kingsley; *nickel,* Ambrose Monell; *oil,* A. C. Bedford; *rubber,* H. S. Hotchkiss; *steel,* Elbert H. Gary; *sulphur,* Henry Whiton; *wool,* Jacob F. Brown; *zinc,* Edgar Palmer; *copper,* John D. Ryan.

The general chemical committee has established headquarters at Washington in charge

of Dr. Wm. H. Nichols, who is devoting all of his time to this work. The committee is cooperating with the Bureau of Mines, the U. S. Geological Survey and the Bureau of Soils in various problems, and all chemical problems are first submitted to this committee. The Manufacturing Chemists' Association of the United States and the National Fertilizer Association have also established offices in Washington in the Woodward Building.

THE AMERICAN PHYSIOLOGICAL SOCIETY AND THE WAR

The following letter has been addressed to members of the American Physiological Society:

The war has thrown upon the members of the national scientific societies unusual responsibilities. The growing conviction among those best fitted to know, that its further continuance will not be brief and that our country must act with her whole energy, makes it clear that every man of science must do his share. Some of the members of the American Physiological Society have entered military service and others are serving the country in a variety of other ways. As the example of England has shown, research is a field in which much can be accomplished, both of immediate relation to the needs of the moment and of permanent value. Under the direction of the committee on physiology of the National Research Council and the Council of National Defense comprehensive investigations of shock, industrial fatigue, food and nutrition, poisonous gases and means of protection from them, and other topics, are already under way. Other subjects demanding investigation will doubtless arise from time to time. The council of the American Physiological Society finds it desirable to know what its members are already doing or are willing to do in the way of national service, whether their laboratories will be open during the coming summer, whether they desire to undertake research in case of need, and, if so, what general lines of research they are prepared to follow. By the authority of the council, therefore, I write to make these inquiries of you. Any suggestions which you may feel like offering in regard to specific lines of research will be welcomed. Please make all records on the enclosed cards and return both to me without delay. The information so obtained will be turned over to the Committee on Physiology of the National Research Council, to be used as seems best. The members of this committee are:

W. H. Howell, *Chairman;*	Frederic S. Lee,
C. L. Alsberg,	Graham Lusk,
W. B. Cannon,	E. G. Martin,
A. J. Carlson,	Walter J. Meek,
Joseph Erlanger,	L. B. Mendel
Theodore Hough,	

In case your services can be utilized you will be duly communicated with.

(Signed) Frederic S. Lee

The registration cards accompanying the letter provided for the following entries:

What national service are you now doing?
Is it likely to continue during the summer?
Will your laboratory be available for research during the summer?
Are you prepared to undertake research for national service and, if so, in what general lines?
Suggestions regarding desirable lines of research.

SCIENTIFIC NOTES AND NEWS

An Anglo-French Scientific Commission which includes Professor Ernest Rutherford, of the University of Manchester, and Professor Henri Abraham, of the University of Paris, is at present in this country to cooporate with American men of science in the development and use of radio-telegraphy.

Secretary of the Navy Daniels has named Dr. William H. Welch, Dr. Flexner and Mr. Nathan Straus, of New York, as a committee to investigate Senator Calder's "round robin charge" that invalided sailors on the hospital ship *Solace* had been subjected to cruelty and neglect.

Dr. E. W. Morley was awarded the Willard Gibbs medal at a recent meeting of the Chicago Section of the American Chemical Society on May 18.

Dr. Richard M. Pearce, professor of research medicine in the University of Pennsylvania, has returned from a tour of three months through Brazil, Argentine and Uraguay to make a study of the medical, hospital, educational and public health conditions in those countries in the interest of the International Health Board of the Rockefeller Foundation.

DR. ALLAN J. MCLAUGHLIN, of Boston, has been appointed to succeed Dr. Richard P. Strong, of Boston, as chairman to the subcommittee on hygiene, medicine and sanitation of the Massachusetts Committee for Public Safety.

DR. MARCUS B. HEYMAN, formerly assistant superintendent of the State Hospital for Insane at Central Islip, L. I., and more recently medical inspector for the State Hospital Commission, has been appointed superintendent of the Manhattan State Hospital at Ward's Island, succeeding the late Dr. William Mabon.

DR. GEORGE DOCK, professor of medicine in the medical school of Washington University (St. Louis), has received the French war cross and has been mentioned for his service in moving wounded soldiers under heavy bombardment while engaged in the American Field Ambulance Service.

WE learn from *The Electrical World* that L. D. Gibbs, chairman, and Frank A. Birch, compose a committee of the National Electric Light Association to secure subscriptions to a fund of $5,000, in recognition of the work of Professor Elihu Thomson. A medal is to be awarded " in any year to any citizen of the United States or Canada who at the time of the award shall not be over thirty-five years of age, and who, in the judgment of the trustees of the medal, shall have made a notable contribution to electrical science or its industrial applications through original investigation, research or discovery, or through whose direct efforts a substantial contribution to the advancement of the industry shall have been accomplished."

FREDERICK BEDELL, professor of applied electricity, of Cornell University, has been elected one of the vice-presidents of the American Institute of Electrical Engineers.

A. W. L. BRAY, assistant professor of biology at the State University of Montana, has been granted leave of absence for one year, to take effect next semester. Professor Bray will engage in biological research work at Harvard University.

PROFESSOR A. B. RECKNAGEL, of the department of forestry of Cornell University, has received a leave of absence from his university duties in order to become forester of the Empire State Forest Products Association. He will take up his new work on July 1 and will establish headquarters for the association at Albany.

PROFESSOR L. B. GILLET, of the department of English literature at Wesleyan University, has resigned his position to enter military service.

PROFESSOR VICTOR GRÉGOIRE (Louvain), and Professor Hans Schinz (Zürich), have been elected foreign members of the Linnean Society.

WE learn from *Nature* that the government Central Control Board of Great Britain has appointed an advisory committee, consisting of Lord D'Abernon (chairman), Sir G. Newman, Dr. A. R. Cushny, Dr. H. H. Dale, Dr. M. Greenwood, Jr., Dr. W. McDougall, Dr. F. W. Mott, Dr. C. S. Sherrington and Dr. W. C. Sullivan, to consider the conditions affecting the physiological action of alcohol, particularly the effects on health and industrial efficiency produced by the consumption of beverages of various alcoholic strengths, with special reference to the recent orders of the Central Control Board, and further to plan out and direct such investigations as may appear desirable with the view of obtaining more exact data on this and cognate questions.

THE National Geographic Society has set aside $12,000 to finance another expedition to Alaska in order to obtain full information in regard to the eruption of Mt. Katmai. The expedition will be in charge of Professor Robert F. Griggs, of the department of botany, The Ohio State University.

MR. JAMES F. COUCH was elected president of the recently organized Des Moines Chemical Society at the regular meeting on April 9.

DEAN W. J. TEETERS, of the University of Iowa, has offered the facilities of the college of pharmacy there for manufacture of drugs and chemicals to be used in the war. He believes that students and faculty can perform

valuable service by making pharmaceutical preparations, pharmaceutical chemicals from raw materials furnished by the government, and in testing the identity and purity of drugs, chemicals and other medical supplies bought by the government in the middle west.

China has instituted a geological survey under the direction of V. K. King, a graduate of the University of Glasgow.

Wm. Mason Towle, professor of industrial engineering at Clarkson College of Technology, Potsdam, N. Y., retires from active service at the close of the present academic year. The trustees have appointed him professor emeritus of industrial engineering.

Mr. Francis C. Shenehon, for the past eight years dean of the College of Engineering of the University of Minnesota and head professor of civil engineering, has opened offices and will give his entire attention to his practise as a consulting hydraulic engineer.

Professor C. K. Leith, of the University of Wisconsin, has recently completed a six weeks' course of lectures on "Metamorphic geology" at the University of Chicago.

Dr. Juan D. Ambrosetti, director of the Ethnographic Museum at Buenos Aires, died on May 28. He was a delegate to the Pan-American Scientific Congress held in Washington in 1915.

Dr. F. F. Ulrik, of Copenhagen, who took the leading part in the movement to provide more hygienic homes for the laboring classes in Denmark, has died at the age of ninety-nine years.

Arrangements have been made for meetings of the Council of the British Association for the Advancement of Science, the General Committee and the Committee of Recommendations to be held in London on July 6, in order to make appointments, receive the report of the Council for the year, and transact other necessary business.

The Spanish government has appropriated the sum of $600,000 for the establishment of a hospital for infectious diseases at Madrid.

At the annual general meeting of the Institution of Civil Engineers of Great Britain, held on April 17, the result of the ballot for the election of officers was declared as follows: *President,* Mr. W. B. Worthington; *Vice-presidents,* Mr. J. A. F. Aspinall, Mr. H. E. Jones, Sir John P. Griffith and Mr. J. A. Brodie; *Other Members of Council,* Dr. C. C. Carpenter, Dr. Dugald Clerk, Colonel R. E. B. Crompton, Mr. M. Deacon, Sir Archibald Denny, Bart., Mr. W. H. Ellis, Sir R. R. Gales, Mr. A. J. Goldsmith, Sir R. A. Hadfield, Brigadier-General B. H. Henderson, Mr. R. W. Holmes, Professor Bertram Hopkinson, Mr. G. W. Humphreys, Mr. Summers Hunter, Dr. W. H. Maw, Mr. C. L. Morgan, Mr. Basil Mott, Sir H. J. Oram, Mr. F. Palmer, Captain H. P. R. Sankey, Sir J. F. C. Snell, Mr. E. F. C. Trench, Mr. W. F. Tye, Sir Philip Watts, Mr. E. J. Way and Sir A. F. Yarrow, Bart. The council has made the following awards for papers read and discussed during the session 1916–17: Telford gold medals to Messrs. G. W. Humphreys and J. B. Ball; George Stephenson gold medals to Messrs. P. V. O'Brien and John Parr; Telford premiums to Messrs. P. V. O'Brien, J. L. Hodgson, W. Brown and P. M. Crosthwaite, and a Crampton prize to Mr. F. J. Waring.

UNIVERSITY AND EDUCATIONAL NEWS

Announcement is made that next year a course in the elements of law, will be given by a professor of the law school of Columbia University to a limited number of qualified students of Barnard College. Certain courses in international law will also be open to specially qualified women.

Beginning with next autumn the Tufts medical school will require two years of regular college work for admission.

We learn from the *American Medical Journal* that fellowships in ophthalmology and otolaryngology in connection with the University of Minnesota have been established by Dr. Frank C. Todd, of Minneapolis, and Dr. Frank E. Burch, of St. Paul, both of the school of medicine. These fellowships carry with them the same stipend that is paid by the University of Minnesota to the university fellows, namely,

$500 the first year, $750 the second year, and $1,000 the third year. Such fellows will spend half their time in the private clinic of Dr. Todd or Dr. Burch, and the other half in laboratory and clinical work and in pursuit of certain courses for specialists in ophthalmology and otolaryngology at the university. For work done in these private clinics, credit will be given toward the degree granted by the university in the course of ophthalmology and otolaryngology given at the University of Minnesota, to accepted doctors of medicine covering a period of three years which prepares the physician for the specialty of ophthalmology and otolaryngology.

THE department of architecture of the University of Illinois is planning to take a leading part in rebuilding storm-stricken Mattoon. Sixteen architects of this department are to draw up sixteen standard plans for houses, the cost of which will range from $800 to $1,400. This work is being done in line with the school for city planning now being arranged for the coming summer. Officers of the university have expressed the hope that the institution may have an opportunity to duplicate on a larger scale in France what is now being done in the city of Mattoon.

PROFESSOR G. H. CLEVENGER, of Stanford University, has been appointed research professor in metallurgy and has been released from elementary and routine teaching.

PROFESSOR JOHN R. ALLEN, head of the department of mechanical engineering of the University of Michigan, has been offered the deanship of the college of engineering and architecture of the University of Minnesota.

MISS PAULINE H. DEDERER, instructor in zoology at Barnard College, has resigned to become assistant professor in biology at the Connecticut College for Women, New London.

DR. P. G. H. BOSWELL, lecturer in geology at the Imperial College of Science and Technology, London, has been appointed the first holder of the George Herdman chair of geology in the University of Liverpool. The establishment of a chair of geology in the university has been long delayed, and is now possible owing to the generosity of Professor and Mrs. Herdman, who have endowed the chair as a memorial to their son, the late Lieutenant George Herdman.

DISCUSSION AND CORRESPONDENCE

THE PHYSIOGRAPHY OF THE LOWER AMAZON VALLEY AS EVIDENCE BEARING ON THE CORAL REEF PROBLEM

THE recent revival of the discussion of the origin of coral reefs[1] has raised many questions which involve not only the coral islands, but also the displacements of the strand lines of the continents throughout the tropics, for the changes in level of the tropical seas invoked by Daly must have been recorded on the continents as well as on the islands. It seems, therefore, that a thorough investigation of at least a considerable number of critically situated continental strands of the tropics must be made before the evidence for or against the acceptance of the glacial control theory may be considered complete.

Recently, in his reading, the writer found an account of the physiography of the lower Amazon valley[2] to which it seems worth while to call attention for the benefit of any who may undertake an investigation of the evidences of strand-line displacements in the tropics.

A brief abstract of a portion of Smith's paper follows: All of the larger rivers entering the lower Amazon from the south, and the Trombetas entering from the north, have lake-like expanses in their lower courses into which the Amazon, at times of flood, is pouring silt which is gradually filling them up. Meanwhile the upper ends of the estuaries are being filled by their own rivers. Some of the latter, which are muddier than others, have already trans-

1 Daly, R. A., "The Glacial Control Theory of Coral Reefs," *Proc. Am. Acad. of Arts and Sciences*, Vol. 51, 1915, 157–251. Davis, W. M., "A Shaler Memorial Study of Coral Reefs," *Am. Jour. Sci.*, 4th ser., Vol. 40, 1915, 223–271. Vaughan, T. Wayland, "The Platforms of Barrier Coral Reefs" (abs.), *Am. Geog. Soc. Bull.*, Vol. 46, 1914, pp. 426–429.

2 Smith, H., "Physical Geography of the Amazon Valley," *Am. Nat.*, Vol. XIX., 1885, 27–37.

formed their former estuaries into alluvial plains above which rise scattered rocky islands. This is particularly true of the northern tributaries of the lower Amazon, except the Trombetas, which has relatively clear water, and has not yet filled its estuary.

The author suggests that the physiographic features described above may be interpreted as the result of a moderate drowning of the region followed by the filling up of the estuary of the Amazon by the heavy silt burden borne by that river:

> Gradually the alluvial land at the head of the bay extended eastward, filling up the estuary with islands. As this eastward movement went on, the branch estuaries were blocked up at their mouths by islands which formed in front of them. Where the branch received a muddy tributary it also filled up; but the clear water tributaries like the Tapajós, Xingú, and Trombetas, brought down no sediment, and their estuaries, closed at the mouths, assumed the form of lakes.

That the phenomena described are the result of changes in level and not merely of the ponding of the tributaries by sediment from the Amazon, is indicated, as the author points out, by the fact that the Tocantins River, which enters the sea directly, has a similar estuary.

The physiographic phenomena here described seem to point to a relatively recent period of lowered sea level (or land uplift) followed by a rise to the present position (or a sinking of the land). The phenomena may have been associated with the changes in sea level postulated by Daly, or they may be due to local crustal movements. Physiographic studies of a large number of tropical rivers would go far toward solving the problem.

John L. Rich

University of Illinois

QUOTATIONS

A PIONEER IN PHYSICS

Forty-seven years of collegiate teaching constitute in themselves a sufficient title to honor, even though their number be only a record of faithful and continuous service. When the passing of these years has told also a story of important pioneer work, of purposeful achievement and steady progress, it becomes a record to conjure with. Of such is the repute that Professor Charles R. Cross has established in the long period of his association with the Massachusetts Institute of Technology, and of such the honor which the institute and all men are glad to accord him as he now lays hold upon the satisfactions of a well-earned retirement. Being graduated from Massachusetts Institute of Technology in 1870, with the third class that went out from its halls, Professor Cross forthwith returned after the summer vacation to take up an instructorship in the department of physics. Upon completing a single year of this service he was made an assistant professor and by 1878 had been given rank as a full professor. In 1886 he became director of the Rogers laboratory and in 1907 was made head of department. It is the threefold mantle of these responsibilities which he wears to-day and which he now contemplates laying aside.

Such accumulated funds of loyalty to his institution, of prestige not only in its counsels but in the scientific world at large, and such skill of investigation and analysis as Professor Cross has acquired, constitute a tangible fortune which might well be assessed only for its large present values. Yet if one is to take his career in review, there must be observed in particular the contribution Professor Cross made to the establishment of electrical engineering as an independent department of modern scientific and technical training. In the early eighties, some time before the wondrous expansion in the practical uses of electricity had generally been foreseen, Professor Cross prophesied it and insisted on electrical studies as part of his teaching in physics. He offered them long before they were taken up by other educators throughout the country, he developed their technique and bore the brunt of a pioneer's labor. Later it was at his instance that Technology introduced the first courses leading to a degree in electrical engineering ever offered in America. All through this development, his influence made for the increasing use and effectiveness of experiments in the illus-

tration of lectures—that most important change of emphasis which came to pass in the method of scientific education. Professor Cross has won high place, which he will hold, whether or not in retirement.—*Boston Evening Transcript.*

SCIENTIFIC BOOKS

The Birds of Britain, their Distribution and Habits. By A. H. EVANS, M.A., F.Z.S., M.B.O.U., Cambridge, 1916. 8vo, pp. xii + 275, numerous halftone text-figures.

This concise and rather informal work is stated to be "primarily intended for schools," but is designed also to serve as a "short handbook which includes the results of the most recent observations, and is adapted to modern nomenclature." While this intention may be justified by the character of the main text, the introductory chapter, treating of "The Class Aves, or Birds in General," might have been written a generation ago, and does not include "the results of the most recent observations," as regards especially the subject of migration. Reference is made only to the creditable work of local observers in Britain, which has accumulated interesting facts regarding the movements of birds in England and Wales without furnishing generalized results, while the important work carried on elsewhere is passed without mention, including the researches of the late W. W. Cooke which have so greatly extended our knowledge of this subject.

In the main text, under the general heading "Classification," with subheadings for the higher groups from orders to subfamilies, a paragraph, without special heading, is devoted usually to each species of regular occurrence in Britain, with a nominal list at the end of nearly 200 "occasional visitors" not formally mentioned in the preceding pages. The author manages to give in the half-page notices of the species of regular occurrence a comprehensive statement of their leading traits, distribution and diagnostic features, in a clear and direct way that should render his "little book" attractive and useful to many readers. The nomenclature is strictly modern, being "almost exactly" that of the British Ornithologist's Union's revised Check-list. The illustrations, though said to be "from photographs taken for the most part from nature," are in many cases obviously not from life but from stuffed specimens or from museum groups, and are thus not up to the standard of the text.

J. A. A.

SPECIAL ARTICLES

FACTORS IN THE GROWTH AND STERILITY OF THE MAMMALIAN OVARY

1. THE growth and, to some extent, the structure of the mammalian ovary depend essentially on the development of the ovarian follicles. The maturation of some follicles and the subsequent rupture leads to the formation of the corpus luteum; the retrogression (atresia) of follicles before they have reached maturity and ruptured leads in certain species to the formation of the so-called interstitial gland and in others to the accumulation of atretic follicles in which the theca interna is relatively prominent, without, however, the formation of an interstitial gland.

As we shall see presently, it is possible to inhibit the full development of the follicles experimentally. Under these conditions we find that the atretic follicles with relatively large thecæ internæ, are especially numerous and constitute perhaps the greater part of the ovary. We may therefore conclude that it is the pressure exerted by the developing, expanding follicles which leads to the shrinking and ultimate complete disappearance of the atretic follicles, and that if this pressure is diminished these atretic follicles become relatively prominent. This explains their relative preponderance in the guinea pig during the period following ovulation, when no large follicles are present in the ovaries.

2. Former observations of the writer showed that under certain conditions mitoses in the granulosa cells of the follicles were especially frequent around the ovum. This suggested the possibility that the stimulus for the growth of the granulosa cells which ultimately determines the growth of the whole follicles, depends upon a substance given off by the ovum. Dr. L. S. N. Walsh in our laboratory

has recently shown quantitatively that during the whole course of the development of the follicles definite relations exist between the ovum and the proliferation of the granulosa cells. These relations can hardly be explained in any other way than as dependent upon a growth stimulus emanating from the ovum and determining the proliferation of the granulosa cells and thus indirectly of the whole follicle. It is possible that in addition to this endogenous growth stimulus certain exogenous stimuli, emanating from other organs with internal secretions (hypophysis?) may be operative. This effect of the ovum on the granulosa cells leads to the formation of the cumulus oophorus, and this structure makes possible the escape of the ovum into the Fallopian tube. Thus the ovum is ultimately the seat of the mechanism which makes possible its fertilization and fixation in the uterine wall.

3. In previous investigations[1] we have shown that it is possible to cause a premature atresia of follicles by the burning out of the corpora lutea. While the effect of moderate heat does not directly destroy the follicles, it diminishes their expansive power; they grow up to a certain point and then become prematurely atretic; the heat causes a mild degree of what might be called a "tissue shock." Under those conditions the development not only of mature, but even of moderately sized follicles, does not take place and as long as this condition lasts the animal is sterile.

4. In continuation of these experiments we found that it is possible to produce the same condition not only by means of a local interference with the ovary, but also by affecting the general state of nutrition through underfeeding the animal. In all cases in which the animals (guinea pigs were used in our experiments) had lost 25 per cent. of their initial weight maturation of the follicles ceased, and in the majority of the cases the follicles became atretic before they had reached even medium size. The changes in the ovary were on the whole more pronounced in younger animals weighing between 300 and 400 grams, but in some cases very marked changes were also produced in older animals. A certain minimum time has to elapse before the changes in the ovary become apparent.

The lack of sufficient food affects in the first place the granulosa cells; they prematurely dissolve. Those granulosa cells, however, which at first escape the solution, continue, as Dr. Walsh found, to divide at approximately the normal rate—another proof of the distinctness of proliferative stimuli and foodstuffs.

The connective tissue becomes affected by the underfeeding somewhat later than the granulosa. This apparent difference in the resistance of different tissues to the effects of underfeeding is of interest and will be tested in further experiments. Thus underfeeding, if very marked, will lead to at least temporary sterility in the guinea pig as an expression of what we designated as a "hypotypical" condition of the ovaries.

5. In one case of pronounced loss of weight following thyroidectomy, we found a still further reaching change. Not only were the ovaries hypotypical, but the stroma separating the various follicles had become affected. It was underdeveloped or lacking in places, so that the thecæ internæ of neighboring follicles in places directly adjoined each other. As a result of this condition and of an imperfect separation of primordial ova, due to the same relative inactivity of the connective tissue, many follicles containing two or more ova developed in both ovaries. It could be clearly seen that small follicles were pushed into the cavity of neighboring follicles as a result of the intraovarian pressure, which, while diminished in hypotypical as compared with normal follicles, was still positive and as a result of the lack of development of ovarian stroma. Follicles containing more than one ovum are occasionally found in the ovaries of various species and it would be of interest to determine whether in addition to the factors operative in our case, other factors may be responsible for this condition in other cases.

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[1] Loeb, Leo, *Zentralblatt f. Physiologie*, 1911, XXV., No. 9. *Virchows Archiv*, 1911, CCVI., 218.

SEGMENTATION IN NEMATODES:

OBSERVATIONS BEARING ON THE UNSETTLED QUESTION OF THE RELATIONSHIP OF NEMATODES TO OTHER BRANCHES OF THE ANIMAL KINGDOM

I HAVE long been impressed by certain evidences of segmentation in nematodes. My first impressions arose from a study of the distribution of the setæ on aquatic forms. This distribution was in those days, and is even yet, described as irregular; the setæ are said to be "scattered" on the body. Charting all the setæ on a given specimen led to the conclusion that they were not scattered ("zerstreut"); that, rather on the contrary, they constituted a series of more or less harmonious groups. The cephalic setæ, it is well known, have an orderly arrangement. The study of a large number of cases leads me to the conclusion that those setæ, some distance behind the cephalic setæ, denominated subcephalic setæ, are also orderly in arrangement, and might, in some instances at least, be regarded as repetitive of the cephalic setæ.

Later I was able to show that the transverse striæ of the cuticle are retrorse on the posterior half of the body, and the reverse on the front half. (See Fig. 1.) This reversal in the cuticle at the middle of the body, or thereabouts, occurs in a very wide range of genera, is independent of age and of sex, and seems a character of fundamental significance.

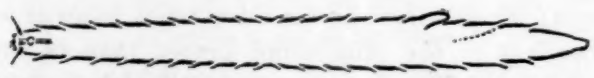

FIG. 1. DIAGRAM OF THE REVERSAL OF THE STRIÆ OF THE CUTICLE OF A NEMATODE.

Recently I have discovered that the principal cephalic organs are made up of segments which, while simple in character, bear no small resemblance to corresponding features in arthropods. The nature of these segmented appendages will be more easily understood by consulting the illustrations in Fig. 2.

The articulations in the cephalic organs of nemas are not easy to discover, owing to the small size of the organs and the transparency of the tissues. Some of these segmented organs are under muscular control, and can be extended and inflexed after the manner of the palps of insects. This is true of some of the labial organs, which unfortunately are usually so small as to be difficult to observe. The cephalic setæ, however, are larger, being particularly well developed on some marine forms, and in this case observation on living specimens affords evidence of the articulations when they might be overlooked if they were sought by other methods; for if a seta is obstructed it takes on the attitude natural to an organ composed of flexible joints and more or less inflexible segments, as shown in the upper illustration, Fig. 2. Here again, once having established the fact and learned how to make the observations, it proves that the setæ of a wide range of genera are jointed, though the number of segments is often reduced to only one or two.

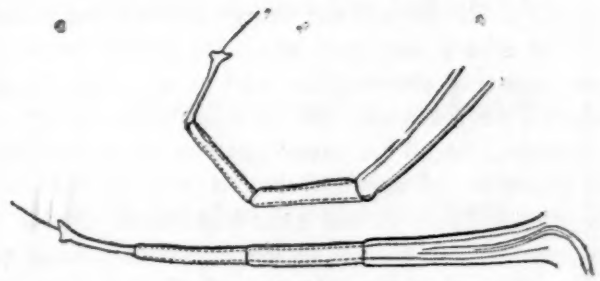

FIG. 2. CEPHALIC SETA OF A NEMATODE, SHOWING SEGMENTATION. TWO DIFFERENT ATTITUDES OF THE SAME SETA.

One recalls that a number of observers have noted the presence of longitudinal series of repetitive organs in the lateral fields of nematodes, though attention has never been called to the fact that these organs on opposite sides of the body may be symmetrical to each other. Sometimes they are exactly so.

N. A. COBB

SOCIETIES AND ACADEMIES

THE BOTANICAL SOCIETY OF WASHINGTON

THE 119th regular meeting of the Botanical Society of Washington was held at the New Ebbitt Hotel, on March 14, 1917. Seventy-four members and sixty-five guests were present. After a dinner President T. H. Kearney introduced the re-

tiring president, A. S. Hitchcock, who addressed the society on "Taxonomic Botany and the Washington Botanist."

The speaker stated that the members of the Botanical Society of Washington are nearly all specialists in the employ of the national government. They must depend upon extra-official opportunities for broadening their outlook and for keeping in touch with the development of botanical research. The speaker brought to their attention the opportunity afforded by a study of the local flora. Every scientist should have training in the two methods for establishing facts, that of experiment and that of repeated observations. The first method is used by the physiologist; the second by the taxonomist. In studying the local flora the Washington botanist can train himself in taxonomic methods and at the same time accumulate valuable botanical data. The speaker outlined the fundamental scope of taxonomic training and called attention to the ways in which the student should apply the general principles to his studies of the local flora. The investigator should free himself from the shackles of authority. He should see things as they are rather than as others say they are. He should learn to make accurate observations and to use these to determine the truth and not to establish a theory or a concept. In all his investigations he should keep his criterion of accomplishment well in advance. He whose ideal is his own best work ceases to progress. Finally the speaker advised young authors, when publishing, to prepare their manuscript with care in regard to clearness, conciseness and technique. Clear thinking leads to clear writing. Care in technique may be taken as an evidence of care in gathering the data which the writing records.

The address will be published in full in the *Journal* of the Washington Academy.

H. L. Shantz,
Corresponding Secretary

THE BIOLOGICAL SOCIETY OF WASHINGTON

The 566th meeting of the society was held in the assembly hall of the Cosmos Club Saturday, February 24, 1917, called to order by President Hay at 8 P.M., with 50 persons in attendance.

Under the heading book notices, brief notes, exhibition of specimens, etc., M. W. Lyon, Jr., called attention to the latest edition of the International Rules of Zoological Nomenclature containing a summary of the opinions that have been rendered by the International Commission, compiled by Mr. John Smallwood, of Washington.

Dr. R. W. Shufeldt communicated a short paper entitled "Notes on the Trunk-fishes" and exhibited a specimen of *Lactophrys tricornis*.

Dr. L. O. Howard commented on the parent tree of an unusually fine variety of oranges and the extraordinary care taken of it by the owner during the recent cold weather in Florida.

Mr. Wm. Palmer also commented on the effects of the recent "freeze" in Florida.

The regular program consisted of three communications as follows:

T. S. Palmer: "A Pioneer Naturalist in Southern Florida—Extracts from the Diary of Titian R. Peale, 1825."

Dr. Palmer gave a detailed account of Peale's collecting trip in Florida in 1825 made for the purpose of securing birds for Prince Louis Bonaparte and mentioned and exhibited the species of birds discovered by Peale as new to science or new to the United States. He read extracts from Peale's diary and called attention to the other scientific expeditions of which Peale was a member giving many interesting facts of his long life.

Some Notes on the Aleyrodidæ: A. L. Quaintance.

The Shad and its Relatives in the Mississippi River: Emerson Stringham (introduced by R. E. Coker).

Mr. Stringham said that herring-like fishes found in the Mississippi River possess more economic significance than formerly recognized. The two mooneyes (*Hiodon*) have flesh of excellent quality, but they are not sufficiently abundant to be of great importance; they eat principally insects, and feed both summer and winter, day and night; they deposit their eggs as soon as the water temperature begins to rise in spring. The gizzard shad (*Dorosoma*) which serves as food for other fishes is less abundant in the Mississippi proper than in slues and lakes. The river herring (*Pomolobus chrysochloris*), known as the host of a mussel of great value, feeds on insects when they are abundant, and on fishes at other times; it breeds early in summer; fears are entertained that the fish and mussel may be excluded from the upper river by a dam at Keokuk, Iowa. The Ohio shad (*Alosa ohiensis*) seems clearly distinct from the Atlantic shad, but is sufficiently similar to be equally good food, though smaller; on the Mississippi this valuable resource is not utilized; the habits of the fish are similar to those of the Atlantic species, but it has not yet been proved to be anadromous.

M. W. Lyon, Jr.,
Recording Secretary